WASTE MANAGEMENT IN A LUNAR BASE

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TASK 4 SUMMARY REPORT

A REVIEW OF ENABLING TECHNOLOGIES FOR TREATMENT OF METABOLIC MATERIALS

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1. INTRODUCTION

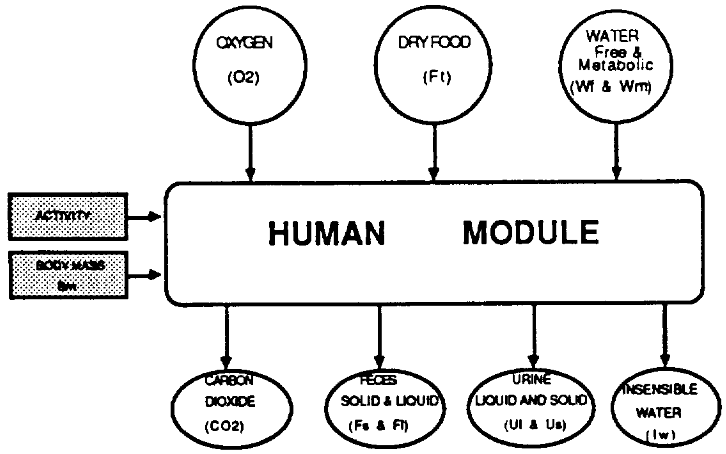
Long-range goals for the space program include the establishment of a man-tended lunar base and human expedition to Mars as the stepping stone toward the expansion of humanity into space and utilization of lunar, Mars and space resources. These missions will be of extended duration and require autonomous life support. The self-sufficiency can be achieved through production of food and recycling of waste products, as resupply from Earth becomes prohibitive in cost.

Autonomy from Earth requires development of an Engineered Closed Ecosystem (ECES), comprised of human, plant and animal modules. The modules must be integrated with a Waste Management System (WMS) to achieve partial and ultimately long-term self-sufficiency. Physical/chemical and/or bioregenerative life support systems are governed by the interfacing of the system modules with the WMS. Processes and alternative enabling technologies for supply of life-support metabolic elements and conversion of metabolic waste elements for utilitarian reuse are reviewed.

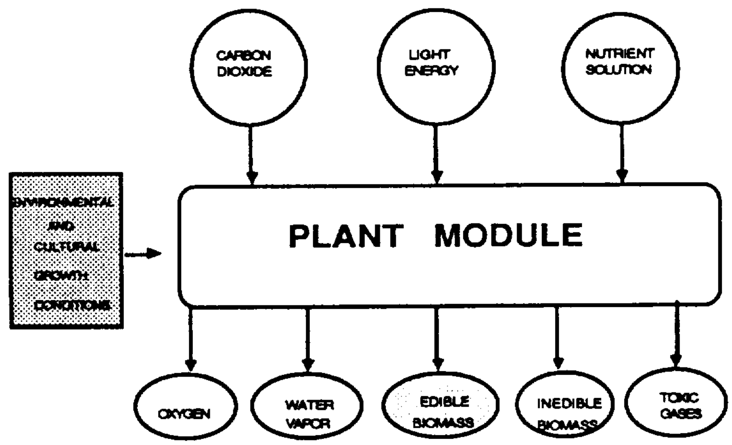
2. INPUT/OUTPUT METABOLIC ELEMENTS

Input/output metabolic elements for each module were outlined in the three previous Task Reports. Schematics of the input/output metabolic elements for human, plant and animal modules are displayed in Fig. 1.

Requirements for the input metabolic elements for the human module are the most critical paramenter for the life-support system. These input metabolic requirements must be fulfilled first, thus "driving" the design of an ECES. Output metabolic elements or metabolic wastes from the human module must be recycled or converted for use as input metabolic elements to any of the modules. Similarly, the output metabolic elements (or metabolic wastes) from the plant and animal modules must be recycled for reuse in any of the other modules.



(a)



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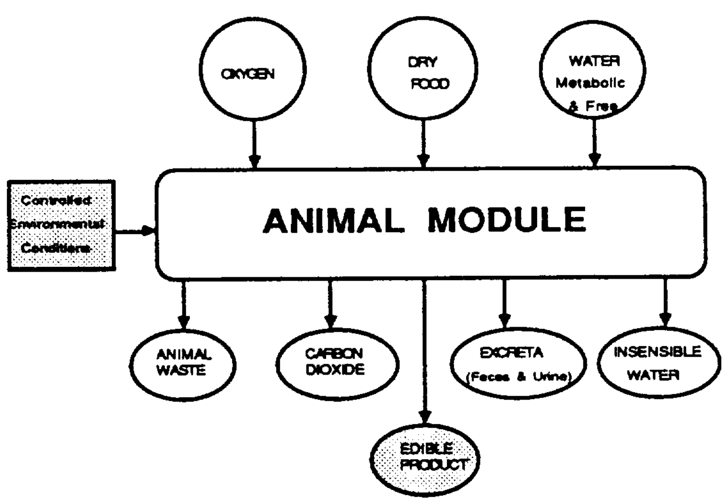

(c)

Fig. 1 Input/output metabolic elements for the three modules.

Any material which can serve as a source for input metabolic elements and any output metabolic element are called raw materials. One or more process alternatives and corresponding enabling technologies are identified for the conversion of each raw material. A conversion is a process causing a "change of state", e.g., from a mixture to a pure substance, from one chemical form to another, from one energy state to another (pressure, temperature). This review identifies the various processes and associated enabling technologies available for supply of input metabolic elements and for conversion of output metabolic elements. The present status of these technologies is further reviewed.

3. METHOD

A method is advanced for selecting enabling technologies to supply life-support metabolic elements and for conversion of output metabolic elements. A top level schematic showing the five steps of this method is given in Fig. 2. The function of each step is stated below:

Step 1. Input/output metabolic elements are identified.

Step 2. Potential raw materials are indicated for each input/output metabolic element.

Step 3. Process alternatives are identified for each raw material.

Step 4. Enabling technologies for each process alternative are identified. Advantages, disadvantages, risks associated with the use, and level of maturity or development are evaluated. These functions are indicated by the side input in Fig.2.

Step 5. Supply/collection enabling technologies for each input/output metabolic element are specified. Further processing, storage or direct use of any metabolic element is indicated as necessary.

This method provides a framework for constructing a matrix that outlines alternative processes and available enabling technologies along with their present status to supply input metabolic elements and to convert metabolic wastes to useful products.

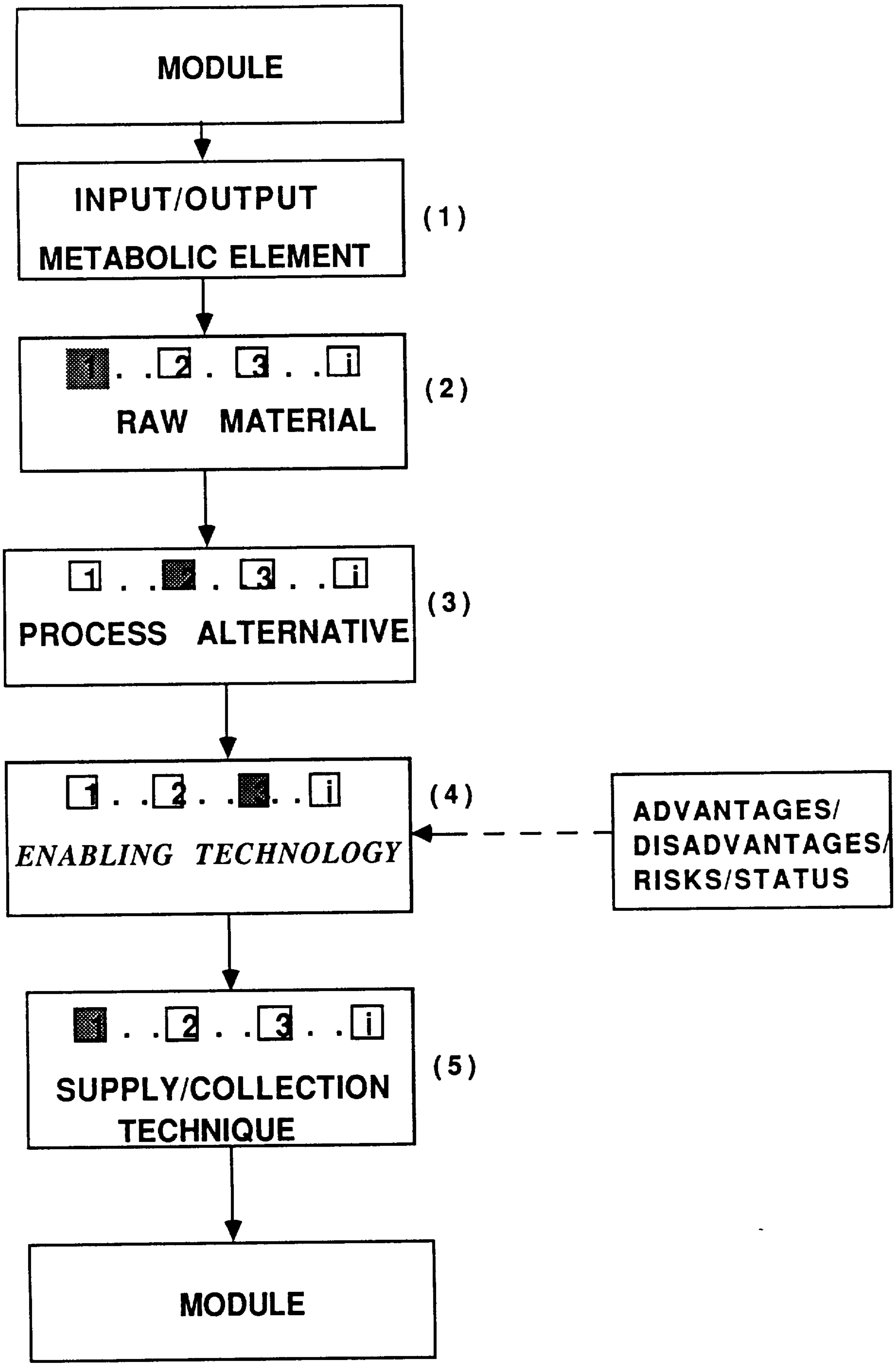

Fig. 2 Method to select enabling technologies.

4. PROCESS ALTERNATIVES/ENABLING TECHNOLOGIES

A variety of process alternatives exist for supply of input metabolic elements and conversion of output metabolic elements for the human, plant and animal modules. One or more enabling technologies are associated with each process alternative. Suitability or ranking of an enabling technology for use in a lunar base is assessed based upon available information

4.1 Metabolic Element Treatment Matrix

Matrices outlining alternative processes and enabling technologies for supply of input metabolic elements and conversion of metabolic wastes from each module are given in Charts 1 through 3. Rows indicate the input/output metabolic elements for each module as delineated in Fig.1. The raw materials, process alternatives, enabling technologies, advantages/disadvantages, risk, current status, supply/collection techniques, ranking and references are given in the columns according to the method outlined in Fig. 2. The function of each column is enumerated in Table 1.

TABLE 1 Function of columns in Charts 1 through 3

Column/Heading	Function
B Input/Output Metabolic Elements	Lists each input/output metabolic element.
C Raw Material	(1) Input metabolic elements: indicates source or sources of raw material. (2) Output metabolic elements: each is classified as a single raw material source.
D Process Alternatives	Specifies process alternatives for treatment of each raw material.
E Enabling Technology	Enumerates one or more enabling technologies associated with each process alternative. Enabling technologies indicated in this column include treatment processes currently under consideration for space missions and terrestrial enabling technologies which may be viable for use in a lunar environment.
F Advantages **G Disadvantages**	Lists advantages and disadvantages of each enabling technology based on its characteristics with respect to operation in a lunar ECES. Attributes of each technology are summarized from a preliminary review of the literature and personal communications.
H Risk	Risks associated with a given enabling technology are specified where applicable. Risks include operational attributes that may affect the crew safety.
I Status	States current development status of each enabling technology.
J Supply/Colleciton Technique	Indicates the supply or collection technique for each input and output metabolic element, respectively.
K Ranking	Specifies a subjective ranking for each enabling technology based upon its advantages/disadvantages, risk and current status.
L References	Lists references used in collecting the data and compiling the information.

4.2 Ranking

Information presented in the metabolic element treatment matrix is utilized to assign rankings to enabling technologies. The rankings are derived from an evaluation of the advantages, disadvantages, operational risk and current status associated with each enabling technology and with respect to its application in a lunar base. All these evaluation criteria are shown in the respective columns in Charts 1 through 3. Ranking values are assigned on a scale of 1 to 10, with 10 being the highest ranking.

Advantages and disadvantages for each enabling technology are ascertained based upon their characteristics (e.g. power, volume, efficiency, pressure requirements, simplicity and/or complexity). Risks which affect crew safety that are associated with the operation of certain enabling technologies are identified where applicable. Fire and/or explosion hazards are examples of risks.

The status of each enabling technology was deduced from a literature review and personal communications. Current status or maturity level varies widely for the various enabling technologies. For example, biological treatment of human feces and urine is mature in the terrestrial environment, but its adaptation to a lunar environment has yet to be investigated. Examples of mature enabling technologies that can be used in space missions for oxygen generation include solid polymer electrolysis and static feed water electrolysis. A higher ranking is assigned to a more mature enabling technology. Review of the current status of available enabling technologies indicates that more research, testing and validation are required before operational flight readiness is achieved.

The rankings offered herein are judgments based upon the current level of knowledge and understanding of the evaluation criteria set forth herein. Future efforts must be undertaken to quantify the performance of each enabling technology based on objective criteria specifically for a lunar base.

5. CONCLUDING REMARKS

A method for selecting available enabling technologies for supply of input metabolic elements to and conversion of output metabolic elements from human, plant and animal modules is proposed. This method permits construction of evaluation matrices for assessment of candidate enabling technologies for use in a lunar base. Data and information are systematically compiled in the matrices in a format conducive to conduct a trade-off evaluation and assessment of the applicability of each enabling technology.

Detailed evaluation matrices were produced for human, plant and animal modules. A preliminary assessment of available enabling technologies was performed based upon a literature review and personal communications. This assessment reveals that basic and applied research is required for even the most mature enabling technologies to bring them to a level of applicability and readiness in space. Increased analytical and experimental research and controlled testing should be undertaken so that more performance data will be available. A linear programming model can then be constructed for objective selection of the appropriate enabling technologies.

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CHART 1-I

	METABOLIC INPUTS	RAW MATERIAL	PROCESS ALTERNAT
INPUTS	1. OXYGEN	1.1 Earth Supplied Oxygen	1.1.1 Not Applicable (N/A)
		1.2 Fuel Cell Oxygen Tank	1.2.1 N/A
		1.3 Plant Module Atmosphere-Gas Mixture	1.3.1 Separation
		1.4 Water	1.4.1 Electrolysis
		1.5 Water Vapor	1.5.1 Produce Oxygen
		1.6 Carbon Dioxide	1.6.1 Electrolysis
	2. DRY FOOD	2.1 Earth Supplied Food	
		2.2 Edible Plant Biomass	2.2.1 Edible Biomass Proces.
		2.3 Edible Animal Product	2.3.1 Edible Product Process
	3. METABOLIC WATER	3.1 From Dry Food Metabolism	3.1.1 N/A
	4. DRINKING WATER	4.1 Imported Water	
		4.2 Fuel Cell Oxygen & Hydrogen Tanks	4.2.1 By-Product Water
		4.3 Water Vapor	4.3.1 Condensation
		4.4 Carbon Dioxide	4.4.1 Reduction
		4.5 Wastewater	4.5.1 Oxidation
			4.5.2 Biological Treatment

FOLDOUT FRAME /

CHART 1-I HUMAN MODULE II

VE	ENABLING TECHNOLOGY	ADVANTA
	1.1.1.1 Cryogenic Storage	Simple-Treatment Not Required
	1.2.1.1 Direct from Spent Fuel Cell	Simple
	1.3.1.1 Active Centrifugal Separation	Low Pressure
	1.3.1.2 Passive Centrifugal Separation	No Moving Parts - Simple - Low Cost - Sep
	1.4.1.1 Solid Polymer Electrolysis	No H_2O/O_2 Separator - Cyclic or Continuou
	1.4.1.2 Static Feed Water Electrolysis	No Condenser/Separator - Cyclic or Contin
	1.5.1.1 Superoxides (MO2(s), where M is an alkiline Earth metal)	Also Acts as CO_2 Scrubber
	1.6.1.1 Carbon Dioxide Electrolysis	No CO_2 Reduction Required - Excellent Ga
	2.1.1.1 Storage	Direct Processed Food Supply
sing	2.2.1.1 Food Preparation (species dependent)	Provides Required Dietary Variety
ing	2.3.1.1 Food Preparation (species dependent)	Provides Required Dietary Variety
	3.1.1.1 N/A	N/A
	4.1.1.1 Storage	Simple - No Treatment Required
	4.2.1.1 Direct from Spent Fuel Cells	Simple
	4.3.1.1 Humidity Control Condensing Heat Exchangers	Simple - High Water Quality
	4.4.1.1 Sabatier Reactor	High Efficiency - Catalyst Remains Activ
	4.4.1.2 Bosch Reactor	Carbon for Atmospheric/Wastewater Tr
	4.4.1.3 Sabatier/Pyrolysis Hybrid	Closure Possible
	4.5.1.1 Supercritical Water Oxidation	99% Efficient - Fast (1 min.) - Salt Sep
	4.5.1.2 Wet Oxidation	Sterile Products - High Water Quality - N
	4.5.1.3 Electrochemical Oxidation	Low Temperature Requirements - High V
	4.6.1.1 Aerobic Oxidation	
	4.6.1.2 Anaerobic Digestion	High Solids in Feed - Methane & Carbo
	4.6.1.3 Composting	Dry Material Treatment

NPUT/OUTPUT METABOLIC ELEMENT ENABLING TECHNOLOGIES FOR A LUNAR BASE

GES	DISADVANTAGES
	Quantity/Weight Penalties - Heat Required
	May Not Be Available
	Moving Mechanical Parts - Energy Required - Separation Efficiency
paration Efficiency	High Pressure
's Operation	High Pressure (115 psi - 3000 psi)
uous Operation	High Pressure (1000 psi)
	Low Efficiency from Overheating Problems (high heat of reaction)
s Separation	Current Technology Problems
	Weight Penalty - Unreliable for Long Missions
	Requires Additional Handling & Processing - Adds Complexity
	Requires Additional Handling & Processing - Adds Complexity
	N/A
	Weight Penalty - Unacceptable for Long Missions
	Unacceptable for Long Missions
	May Require Post-treatment for Chemical & Biological Impurities
e	Methane Treatment/Disposal - No Closure Possible
eatment-Closure Possible	Low Efficiency - Catalyst Activation Required
	Process Requires Two Steps
ration in Aqueous Phase	Temperature (377 C), Pressure (3000 psi), Power, Heat Rejection, Weight & Volume
H_3 for Plants Produced - Automatic	Temperature (300 C), Pressure (2000 psi) - Requires VPCAR Subsystem
alue Chemical Feedstock Produced	N_2 Produced
	Energy Required - Low Solids - Toxic Upset Possible - Volume - Lead Time Required
n Dioxide Produced	Toxic Upset Possible - Volume - Lead Time Required - Time of Cycle
	Volume

RISK	STATUS
Fire	System Operational - Backup Source
	System Operational (?)
	Prototype System Operational (?) - Research Required
Explosion	Prototype System Operational (?) - Research Required
Explosion	Six Person Preprototype has Been Tested - Tradeoff Analysis Required
Explosion	Multiman Module Level has Been Tested - Tradeoff Analysis Required
	Only KO2, Tested in Self Contained Breathing Apparatus - Research Required
	Early Development Stage - Considered for Space Station Safe Haven - Research Required
	System Operational - Required for Startup of Lunar Base ECES
	Not Tested for Space Environment - Research Required
	Not Tested for Space environment - Research Required
N/A	N/A
	Used for Short Duration Space Missions - Required for Backup
	Used for Short Duration Space Missions - Required for Backup
	System Operational - Tradeoff Analysis Required
	Five Person Preprototype, Gravity Independent Tested - Tradeoff Analysis Required
	Hardware Available, Not Well Tested - Tradeoff Analysis Required
Explosion	Early Devleopment Stage - Dilute or Concentrated Slurry Feed - Research Required
Explosion	Four Man Prototype for Space Habitats Built and Tested - Tradeoff Analysis Required
	Limited Laboratory Testing - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required

FOLDOUT FRAME 4

CHART 1-I

SUPPLY TECHNIQUE	RANKING	REFERENCES
1.1.1.1(1) From Storage	5	1
1.2.1.1(1) Oxygen Excess from Fuel Cell	8	1
1.3.1.1(1) Direct/Storage	5	2
1.3.1.2(1) Direct/Storage	7	2
1.4.1.1(1) Direct/Storage	7	1;3
1.4.1.2(1) Direct/Storage	8	1;3
1.5.1.1(1) Direct/Storage	2	1
1.6.1.1(1) Direct/Storage	3	1
2.1.1.1(1) From Storage	5	
2.2.1.1(1) Direct/Storage	5	14
2.3.1.1(1) Direct/Storage	5	11
N/A	N/A	N/A
4.1.1.1(1) Carried Storage	5	1;4;5
4.2.1.1(1) Direct/Storage	8	1
4.3.1.1(1) Direct/Storage	7	1
4.4.1.1(1) Direct/Storage	8	1;3
4.4.1.2(1) Direct/Storage	6	1;3
4.4.1.3(1) Direct/Storage	5	3
4.5.1.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	1;3;6;7
4.5.1.2(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	8	1;3;7
4.5.1.3(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
	1	9
	1	9
	1	9

FOLDOUT FRAME 5

CHART 1-O		
METABOLIC OUTPUTS	RAW MATERIAL	PROCESS ALTERNATIVE
1. CARBON DIOXIDE	1.1 Gas Mixture	1.1.1 Separation
		1.1.2 Separation & Concentration
2. FECES	2.1 Feces	2.1.1 Incineration
		2.1.2 Oxidation
		2.1.3 Biological Treatment
		2.1.4 Solidification
3. URINE	3.1 Urine	3.1.1 Distillation
		3.1.2 Filtration
		3.1.3 Oxidation
		3.1.4 Adsorption
		3.1.5 Fuel Cell
		3.1.6 Biological Treatment
4. INSENSIBLE WATER	4.1 Insensible Water	4.1.1 Condensation

OUTPUTS

FOLDOUT FRAME

CHART 1-O HUMAN MODULE

ENABLING TECHNOLOGY	ADVANTA(
1.1.1.1 Lithium Hydroxide	Simple
1.1.2.1 Active Centrifugal Separation	Low Pressure
1.1.2.2 Passive Centrifugal Separation	No Moving Parts - Simple - Low Cost - Separ
1.1.2.3 Molecular Sieve	Reversible - Waste Heat Regeneration
1.1.2.4 Electrochemical Depolarized Concentrator	Continuous/Cyclic Removal - Generates DC P
1.1.2.5 Solid Amine Resin	No H_2 or H_2O Removal Required
1.1.2.6 Membrane	Low Energy & Heat Rejection
2.1.1.1 Dry Incineration	Sterile Products - Ambient Pressure
2.1.2.1 Supercritical Water Oxidation	99% Efficient - Fast (1 min.) - Salt Separatio
2.1.2.2 Wet Oxidation	Sterile Products - High Water Quality - NH_3 f
2.1.2.3 Electrochemical Oxidation	Low Temperature Requirements - High Value
2.1.3.1 Aerobic Oxidation	
2.1.3.2 Anaerobic Digestion	High Solids in Feed
2.1.4.1 Microwave Treatment	Simple
3.1.1.1 Vapor Compression Distillation (VCD)	Low Power - High Heat & Water Recovery -
3.1.1.2 Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES)	Simple - Low Power - High Heat & Water Re
3.1.1.3 Vapor Phase Catalytic Ammonia Removal (VPCAR)	High Water Quality & Heat Recovery
3.1.2.1 Reverse Osmosis (RO)	Low Power - No Gas/Liquid Separator - High
3.1.2.2 Multifiltration	Simple - Low Pressure
3.1.3.1 Electrochemical Oxidation	Low Temperature Requirements - High Value
3.1.4.1 Activated Carbon	Simple - Well Understood
3.1.5.1 BioChem Fuel Cell	Energy for Fuel
3.1.6.1 Aerobic Oxidation	
3.1.6.2 Anaerobic Digestion	High Solids in Feed - Carbon Dioxide and Me
4.1.1.1 Humidity Control Condensing Heat Exchangers	Simple - High Water Quality

FOLDOUT FRAME 2

NPUT/OUTPUT METABOLIC ELEMENT ENABLING TECHNOLOGIES FOR A LUNAR BASE

ES	DISADVANTAGES
	Irreversible - Expendibles Required - Unacceptable for Long Missions
	Moving Mechanical Parts - Energy Required - Separation Efficiency
ation Efficiency	High Pressure
	Recycle Energy Required - Periodic "Bake Out" Required
·wer - H_2O Removal Not Required	Requires Oxygen Regeneration Subsystem
	High Heat Rejection - Requires Steam & Recycle
	Temperature (540 C) - VPCAR Required - Manual Load - N_2, Oxides of N Produced
in Aqueous Phase	Temperature (377 C), Pressure (3000 psi), Power, Heat Rejection, Weight & Volume
Plants Produced - Automatic	Temperature (300 C), Pressure (2000 psi) - Requires VPCAR Subsystem
:hemical Feedstock Produced	N_2 Produced
	Low Solids - Toxic Upset Possible - Lead Time Required
	Toxic Upset Possible - Lead Time Required
	Requires Disposal (i.e. waste not recycled) of Solidified Waste
igher capacity than TIMES	Low Water Quality - Cannot Process Solids
overy	Low Water Quality - Cannot Process Solids
	Temperature (up to 450 C), Power (217 W h/kg) H_2O - Volume - Cannot Process Solids
Vater Recovery	Pressure (100 to 800 psi) - Low Throughput (membrane variable) - Disposal of Rejection
	Expendibles Required to Regenerate Ion Exchange Beds
:hemical Feedstock Produced	N_2 Produced
	Regeneration Required - Salts Not Removed
	Low Solids - Toxic Upset Possible - Lead Time Required
iane Produced	Toxic Upset Possible - Lead Time Required
	May Require Post-treatment for Chemical & Biological Impurities

RISK	STATUS
	Used in Short Duration Space Missions - Removes Only Carbon Dioxide
	Prototype System Operational - Research Required
Explosion	Prototype System Operational - Research Required
	Used on Skylab - Tradeoff Analysis Required
	Highly Developed - Tradeoff Analysis Required
	Tested for Submarine Air Purification - Tradeoff Analysis Required
	Early Development Stage - Research Required
Fire	Four Man System Built & Tested - Waste Feed About 50% Solids - Research Required
Explosion	Early Development Stage - Dilute or Concentrated Slurry Feed - Research Required
Explosion	Four Man Prototype for Space Habitats Built and Tested - Tradeoff Analysis Required
	Limited Laboratory Testing - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	Paper Examination - Research Required
	Prototype Operational - Tradeoff Analysis Required
	Three Person Prototype Built & Tested - Tradeoff Analysis Required
	Under Development - Research Required
Explosion	Not Tested for Space Environment - Research Required
	Used in Ground-Based Manned Chambers - Research Required
	Limited Laboratory Testing - Research Required
	Not Tested for Space Environment - Research Required
	Early Development Stage - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	System Operational - Tradeoff Analysis Required

FOLDOUT FRAME 4

		CHART 1-O
COLLECTION TECHNIQUE	RANKING	REFERENCES
1.1.1.1(1) Separation, Stored on LiOH	2	1
1.1.2.1(1) Direct/Storage	5	2
1.1.2.2(1) Direct/Storage	7	2
1.1.2.3(1) Carbon Dioxide Subsystems - Plant Module	7	1;3
1.1.2.4(1) Carbon Dioxide Subsystems - Plant Module	7	1;3
1.1.2.5(1) Carbon Dioxide Subsystems - Plant Module	6	1;3
1.1.2.6(1) Carbon Dioxide Subsystems - Plant Module	3	3
2.1.1.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	7	1;3;7
4.5.1.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	1;3;6;7
4.5.1.2(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	8	1;3;7
4.5.1.3(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
	1	9
	1	9
	1	2
3.1.1.1(1) Direct/Storage	8	1;3;4;7
3.1.1.2(1) Direct/Storage	7	1;3;7;10
3.1.1.3(1) Direct/Storage	6	1;3;7
3.1.2.1(1) Direct/Storage	5	1;3
3.1.2.2(1) Direct/Storage	5	1;3;5
3.1.3.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
3.1.4.1(1) Direct/Storage	3	3
3.1.5.1(1) Direct/Storage	2	3
	1	9
	1	9
4.1.1.1(1) Direct/Storage	7	3

CHART 2-I

INPUTS	METABOLIC INPUTS	RAW MATERIAL	PROCESS ALTERNATIVE
	1. CARBON DIOXIDE	1.1 Stored Carbon Dioxide	1.1.1 Not Applicable (N/A)
		1.2 Human & Animal Module Mixed Gases	1.2.1 Separation & Concentration
	2. LIGHT ENERGY	2.1 Radiation	2.1.1 Solar
			2.1.2 Artificial
	3. NUTRIENT SOLUTION	3.1 Imported Micronutrients	3.1.1 N/A
		3.2 Human Feces	3.2.1 Incineration
			3.2.2 Oxidation
			3.2.3 Biological Treatment
		3.3 Human Urine	3.3.1 Distillation
			3.3.2 Filtration
			3.3.3 Oxidation
			3.3.4 Adsorption
			3.3.5 Fuel Cell
			3.3.6 Biological Treatment
		3.4 Animal Excreta	3.4.1 Same as for Human Feces & Urine

FOLDOUT FRAME

CHART 2-I PLANT MOD

ENABLING TECHNOLOGY	ADVAN
1.1.1.1 Cryogenic Storage	Direct from Stored CO_2
1.2.1.1 Molecular Sieve	Reversible - Waste Heat Regeneration
1.2.1.2 Electrochemical Depolarized Concentrator	Continuous/Cyclic Removal - Generates
1.2.1.3 Solid Amine Resin	No H_2 or H_2O Removal Required
1.2.1.4 Membrane	Low Energy & Heat Rejection
1.2.1.5 Active Centrifugal Separation	Low Pressure
1.2.1.6 Passive Centrifugal Separation	No Moving Parts - Simple - Low Cost - S
2.1.1.1 Fresnel Fiber Optic Cable Solar Collector	Lowers System Energy Cost - Radiation
2.1.1.2 Incandescent Radiation (e.g. High Pressure Sodium Lamps)	Efficient Energy Use
2.1.1.3 Flourescent Radiation	Lower Thermal Lad to Plant Module
3.1.1.1 Storage	Provides Necessary Nutrients to Optimiz
3.2.1.1 Dry Incineration	Sterile Products
3.2.2.1 Supercritical Water Oxidation	99% Efficient - Fast (1 min.) - Salt Sepa
3.2.2.2 Wet Oxidation	Sterile Products - High Water Quality - N
3.2.2.3 Electrochemical Oxidation	Low Temperature Requirements - High V
3.2.3.1 Aerobic Oxidation	
3.2.3.2 Anaerobic Digestion	High Solids in Feed - Methane & Carbon
3.2.3.3 Composting	Dry Material Treatment
3.3.1.1 Vapor Compression Distillation (VCD)	Low Power - High Heat & Water Recover
3.3.1.2 Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES)	Simple - Low Power - High Heat & Water
3.3.1.3 Vapor Phase Catalytic Ammonia Removal (VPCAR)	High Water Quality & Heat Recovery
3.3.2.1 Reverse Osmosis (RO)	Low Power - No Gas/Liquid Separator - H
3.3.2.2 Multifiltration	Simple - Low Pressure
3.3.3.1 Electrochemical Oxidation	Low Temperature Requirements - High Va
3.3.4.1 Activated Carbon	Simple - Well Understood
3.3.5.1 BioChem Fuel Cell	Energy for Fuel
3.3.6.1 Aerobic Oxidation	
3.3.6.2 Anaerobic Digestion	High Solids in Feed - Methane & Carbon D

FOLDOUT FRAME 2

ULE INPUT/OUTPUT METABOLIC ELEMENT ENABLING TECHNOLOGIES FOR A LUNAR BASE

TAGES	DISADVANTAGES
	Weight Penalty - Energy Required
	Recycle Energy Required - Periodic "Bake Out" Required
DC Power - H_2O Removal Not Required	Requires Oxygen Regeneration Subsystem
	High Heat Rejection - Requires Steam & Recycle
	Moving Mechanical Parts - Energy Required - Separation Efficiency
eparation Efficiency	High Pressure
Frequency can be Specified	Weight Penalty - Not Operational During Dark Periods
	High Thermal Loads Require Dissipation - Energy Required
	Less Efficient - Lower Intensity - Energy Required
e Plant Growth	Weight Penalty
	Effluent Treatment - VPCAR & Manual Load Required - N_2 & Nox Produced
ation in Aqueous Phase	Temperature (377 C), Pressure (3000 psi), Power, Heat Rejection, Weight & V
H_3 for Plants Produced - Automatic	Temperature (300 C), Pressure (2000 psi) - Requires VPCAR Subsystem
alue Chemical Feedstock Produced	N_2 Produced
	Energy Required - Low Solids - Toxic Upset Possible - Volume - Lead Time Req
Dioxide Produced	Toxic Upset Possible - Volume - Lead Time Required - Time of Cycle
	Volume
y - Higher Capacity than TIMES	Low Water Quality - Cannot Process Solids
Recovery	Low Water Quality - Cannot Process Solids
	Temperature (up to 450 C), Power (217 W h/kg) H_2O - Volume - Cannot Proce.
igh Water Recovery	Pressure (100 to 800 psi) - Low Throughput (membrane variable) - Disposal of
	Expendibles Required to Regenerate Ion Exchange Beds
lue Chemical Feedstock Produced	N_2 Produced
	Regeneration Required - Salts not Removed
	Energy Required - Low Solids - Toxic Upset Possible - Volume - Lead Time Requ
ioxide Produced	Toxic Upset Possible - Volume - Lead Time Required - Time of Cycle

	RISK	STATUS
		System Operational
		Operationl on Skylab - Tradeoff Analysis Required
		Highly Developed - Tradeoff Analysis Required
		Tested for Submarine Air Purification - Tradeoff Analysis Required
		Early Development Stage - Research Required
		Prototype System Operational - Research Required
	Explosion	Prototype System Operational - Research Required
		Combination of Solar/Artificial Radiation Likely - Research Required
		Combination of Solar/Artificial Radiation Likely - Research Required
		Combination of Solar/Artificial Radiation Likely - Research Required
	Fire	Four Man System Built & Tested - Waste Feed About 50% Solids - Research Required
olume	Explosion	Early Development Stage - Dilute or Concentrated Slurry Feed - Research Required
	Explosion	Four Man Prototype for Space Habitats Built and Tested - Tradeoff Analysis Required
		Limited Laboratory Testing - Research Required
uired		Not Tested for Space Environment - Research Required
		Not Tested for Space Environment - Research Required
		Not Tested for Space Environment - Research Required
		Prototype Operational - Tradeoff Analysis Required
		Three Person Prototype Built & Tested - Tradeoff Analysis Required
ss Solids		Under Development - Tradeoff Analysis Required
Rejection	Explosion	Not Tested for Space Environment - Research Required
		Used in Ground-Based Manned Chambers - Research Required
		Limited Laboratory Testing - Research Required
		Not Tested for Space Environment - Research Required
		Early Development Stage - Research Required
ired		Not Tested for Space Environment - Research Required
		Not Tested for Space Environment - Research Required

	CHART 2-I	
SUPPLY TECHNIQUE	RANKING	REFERENCES
1.1.1.1(1) Carbon Dioxide Storage	5	1
1.2.1.1(1) Carbon Dioxide Subsystem - Plant Module	7	1;3
1.2.1.2(1) Carbon Dioxide Subsystem - Plant Module	7	1;3
1.2.1.3(1) Carbon Dioxide Subsystem - Plant Module	6	1;3
1.2.1.4(1) Carbon Dioxide Subsystem - Plant Module	3	3
1.2.1.5(1) Carbon Dioxide Subsystem - Plant Module	5	2
1.2.1.6(1) Carbon Dioxide Subsystem - Plant Module	7	2
2.1.1.1(1) Solar Collectors - Fiber Optics	5	12
2.1.1.2(1) Internal Power System	7	12
2.1.1.3(1) Internal Power System	5	12
3.2.1.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	7	1;3;7
3.2.2.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	1;3;6;7
3.2.2.2(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	8	1;3;7
3.2.2.3(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
	1	9
	1	9
	1	9
3.3.1.1(1) Direct/Storage	8	1;3;4;7
3.3.1.2(1) Direct/Storage	7	1;3;7;10
3.3.1.3(1) Direct/Storage	6	1;3;7
3.3.2.1(1) Direct/Storage	5	1;3
3.3.2.2(1) Direct/Storage	5	1;3;5
3.3.3.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	8
3.3.4.1(1) Direct/Storage	3	3
3.3.5.1(1) Direct/Storage	2	3
	1	9
	1	9
	See Chart 1	

	CHART 2-O		
OUTPUTS	METABOLIC OUTPUTS	RAW MATERIAL	PROCESS ALTERNATIVE
	1. OXYGEN	1.1 Gas Mixture	1.1.1 Centrifugal Separation
	2. TRANSPIRED WATER	2.1 Water Vapor	2.1.1 Condensation
	3. EDIBLE BIOMASS	3.1 Harvested Plants	3.1.1 Processing for Human Consumption
			3.1.2 Processing for Animal Consumption
	4. INEDIBLE BIOMASS	4.1 Harvested Plants	4.1.2 Incineration
			4.1.3 Oxidation
	5. TOXIC GASES	5.1 Plant Module Atmosphere	5.1.1 Adsorption/Oxidation

FOLDOUT FRAME 1

CHART 2-O PLANT MODULE INPUT/O

ENABLING TECHNOLOGY	ADVANTAGES
1.1.1.1 Active Centrifugal Separation	Low Pressure
1.1.1.2 Passive Centrifugal Separation	No Moving Parts - Simple - Low Cost - Separation Efficie
2.1.1.1 Humidity Control Condensing Heat Exchangers	Simple - High Water Quality
3.1.1.1 Species Dependent	Provides Dietary Requirements - Psychological Benefits
3.1.2.1 Species Dependent	Animal Dietary Requirements
4.1.2.1 Dry Incineration	Sterile Products
4.1.3.1 Supercritical Water Oxidation	99% Efficient - Fast (1 min.) - Salt Separation in Aqueo
4.1.3.2 Wet Oxidation	Sterile Products - High Water Quality - NH_3 for Plants Pr
4.1.3.3 Electrochemical Oxidation	Low Temperature Requirements - High Value Chemical F
5.1.1.1 Activated Charcoal/High Temperature Catalytic Oxidizer	Removes Well Adsorbed Contaminants, Ammonia, and \

FOLDOUT FRAME 2

UTPUT METABOLIC ELEMENT ENABLING TECHNOLOGIES FOR A LUNAR BASE

	DISADVANTAGES
	Moving Mechanical Parts - Energy Required - Separation Efficiency
ncy	High Pressure
	May Require Post-treatment for Chemical & Biological Impurities
	Requires Processing - Adds Complexity
	Requires Processing - Adds Complexity
	Effluent Treatment - VPCAR & Manual Load Required - N_2 & Oxides of Nitrogen Produced
ıs Phase	Temperature (377 C), Pressure (3000 psi), Power, Heat Rejection, Weight & Volume
oduced - Automatic	Temperature (300 C), Pressure (2000 psi) - Requires VPCAR Subsystem
ˈeedstock Produced	N_2 Produced
Vater Soluable Contents	Temperature (> 700 K) - Acidic Compounds May be Produced

FOLDOUT FRAME 3

RISK	STATUS
	Prototype System Operational - Research Required
Explosion	Prototype System Operational - Research Required
	System Operational - Tradeoff Analysis Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
Fire	Four Man System Built & Tested - Waste Feed About 50% Solids - Research Required
Explosion	Early Development Stage - Dilute or Concentrated Slurry Feed - Research Required
Explosion	Four Man Prototype for Space Habitats Built and Tested - Tradeoff Analysis Required
	Limited Laboratory Testing - Research Required
	Prototype Subsystem for Simulated Human Loading Built & Tested - Research Required

FOLDOUT FRAME 4

		CHART 2-O
COLLECTION TECHNIQUE	RANKING	REFERENCES
1.1.1.1(1) Direct/Storage	7	2
1.1.1.2(1) Direct/Storage	5	2
2.1.1.1(1) Water/Storage	7	
3.1.1.1(1) Direct/Storage	5	
3.1.2.1(1) Direct/Storage	5	
4.1.2.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	7	1;3;7
4.1.3.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	1;3;6;7
4.1.3.2(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	8	1;3;7
4.1.3.3(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
5.1.1.1(1) Recirculation of Treated Atmosphere	5	1

FOLDOUT FRAME 5

	CHART 3-I		
INPUTS	METABOLIC INPUTS	RAW MATERIAL	PROCESS ALTERNA
	1. OXYGEN	1.1 Earth Supplied Oxygen	1.1.1 Not Applicable (N/
		1.2 Fuel Cell Oxygen Tank	1.2.1 N/A
		1.3 Plant Module Atmosphere-Gas Mixture	1.3.1 Separation
		1.4 Water	1.4.1 Electrolysis
		1.5 Water Vapor	1.5.1 Produce Oxygen
		1.6 Carbon Dioxide	1.6.1 Electrolysis
	2. DRY FOOD	2.1 Earth Supplied Food	2.1.1 N/A
		2.2 Edible Plant Biomass	2.2.1 Edible Biomass Pro
		2.3 Edible Animal Waste	2.3.1 Hydrolysis
	3. METABOLIC WATER	3.1 From Dry Food Metabolism	3.1.1 N/A
	4. DRINKING WATER	4.1 Earth Supplied Water	
		4.2 Fuel Cell Oxygen & Hydrogen Tanks	4.2.1 By-Product Water
		4.3 Water Vapor	4.3.1 Condensed Water V
		4.4 Carbon Dioxide	4.4.1 Reduction
		4.5 Wastewater	4.5.1 Oxidation
			4.5.2 Biological Treatment

FOLDOUT FRAME 1

CHART 3-I ANIMAL MOD

TIVE	ENABLING TECHNOLOGY	ADVA
A)	1.1.1.1 Cryogenic Storage	Simple - Treatment Not Required
	1.2.1.1 Direct from Spent Fuel Cell	Simple - Treatment Not Required
	1.3.1.1 Active Centrifugal Separation	Low Pressure
	1.3.1.2 Passive Centrifugal Separation	No Moving Parts - Simple - Low Cos
	1.4.1.1 Solid Polymer Electrolysis	No H_2O/O_2 Separator - Cyclic or Cor
	1.4.1.2 Static Feed Water Electrolysis	No Condenser/Separator - Cyclic or
	1.5.1.1 Superoxides (MO2(s), where M is an alkiline Earth metal)	Also Acts as CO_2 Scrubber
	1.6.1.1 Carbon Dioxide Electrolysis	No CO_2 Reduction Required - Excell
	2.1.1.1 Storage	Direct Processed Food Supply
cessing	2.2.1.1 Food Preparation (species dependent)	Provides Required Dietary Variety
	2.3.1.1 Hydrolysis	Recycle Animal Waste for Direct Fe
	3.1.1.1 N/A	N/A
	4.1.1.1 Storage	Simple - No Treatment Required
	4.2.1.1 Direct from Spent Fuel Cells	Simple
apor	4.3.1.1 Humidity Control Condensing Heat Exchangers	Simple - High Water Quality
	4.4.1.1 Sabatier Reactor	High Efficiency - Catalyst Remains
	4.4.1.2 Bosch Reactor	Carbon for Atmospheric/Wastewate
	4.4.1.3 Sabatier/Pyrolysis Hybrid	Closure Possible
	4.5.1.1 Supercritical Water Oxidation	99% Efficient - Fast (1 min.) - Salt
	4.5.1.2 Wet Oxidation	Sterile Products - High Water Qualit
	4.5.1.3 Electrochemical Oxidation	Low Temperature Requirements - Hi
	4.5.2.1 Aerobic Oxidation	
	4.5.2.2 Anaerobic Digestion	High Solids in Feed - Methane & Ca
	4.5.2.3 Composting	Dry Material Treatment

ULE INPUT/OUTPUT METABOLIC	ELEMENT ENABLING TECHNOLOGIES FOR A LUNAR BASE
NTAGES	DISADVANTAGES
	Quantity/Weight Penalties - Heat Required
	May Not Be Available
	Moving Mechanical Parts - Energy Required - Separation Efficiency
st - Separation Efficiency	High Pressure
tinuous Operation	High Pressure (115 psi - 3000 psi)
Continuous Operation	High Pressure (1000 psi)
	Low Efficiency from Overheating Problems (high heat of reaction)
ent Gas Separation	Current Technology Problems
	Weight Penalty - Unreliable for Long Missions
	Requires Additional Handling & Processing - Adds Complexity
ed Product	Biomagnification of Toxins in Feed Supply
	N/A
	Weight Penalty - Unacceptable for Long Missions
	Unacceptable for Long Missions
	May Require Post-treatment for Chemical & Biological Impurities
Active	Methane Treatment/Disposal - No Closure Possible
r Treatment-Closure Possible	Low Efficiency - Catalyst Activation Required
	Process Requires Two Steps
Separation in Aqueous Phase	Temperature (377 C), Pressure (3000 psi), Power, Heat Rejection, Weight & Volume
y - NH_3 for Plants Produced - Automatic	Temperature (300 C), Pressure (2000 psi) - Requires VPCAR Subsystem
gh Value Chemical Feedstock Produced	N_2 Produced
	Energy Required - Low Solids - Toxic Upset Possible - Volume - Lead Time Required
rbon Dioxide Produced	Toxic Upset Possible - Volume - Lead Time Required - Time of Cycle
	Volume

RISK	**STATUS**
Fire	Backup Source
	Prototype System Operational - Research Required
Explosion	Prototype System Operational - Research Required
Explosion	Six Person Preprototype has Been Tested - Tradeoff Analysis Required
Explosion	Multiman Module Level has Been Tested - Tradeoff Analysis Required
	Only KO2, Tested in Self Contained Breathing Apparatus - Research Required
	Early Development Stage - Considered for Space Station Safe Haven - Research Required
	Required for Startup of Lunar Base ECES
	Not Tested for Space Environment - Research Required
	Not Tested for Space environment - Research Required
N/A	N/A
	Required for Backup
	Has been used for Missions < 60 Days - May not be Available
	Five Person Preprototype, Gravity Independent Tested - Tradeoff Analysis Required
	Hardware Available, Not Well Tested - Tradeoff Analysis Required
Explosion	Early Devleopment Stage - Dilute or Concentrated Slurry Feed - Research Required
Explosion	Four Man Prototype for Space Habitats Built and Tested - Tradeoff Analysis Required
	Limited Laboratory Testing - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required

FOLDOUT FRAME 4.

		CHART 3-I
SUPPLY TECHNIQUE	RANKING	REFERENCES
1.1.1.1(1) From Storage	5	1
1.2.1.1(1) Oxygen Excess from Fuel Cell	8	1
1.3.1.1(1) Direct/Storage	7	2
1.3.1.2(1) Direct/Storage	5	2
1.4.1.1(1) Direct/Storage	7	1;3
1.4.1.2(1) Direct/Storage	8	1;3
1.5.1.1(1) Direct/Storage	2	1
1.6.1.1(1) Direct/Storage	3	1
2.1.1.1(1) From Storage	5	
	5	14
2.3.1.1(1) Direct/Storage	2	11
N/A	N/A	N/A
4.1.1.1(1) From Storage	5	1;4;5
4.2.1.1(1) Direct/Storage	8	1
4.3.1.1(1) Direct/Storage	7	
4.4.1.1(1) Direct/Storage	8	1;3
4.4.1.2(1) Direct/Storage	6	1;3
4.4.1.3(1) Direct/Storage	5	3
4.5.1.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	1;3;6;7
4.5.1.2(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	8	1;3;7
4.5.1.3(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
	1	9
	1	9

	CHART 3-O		
OUTPUTS	METABOLIC OUTPUTS	RAW MATERIAL	PROCESS ALTERNATIVE
	1. CARBON DIOXIDE	1.1 Gas Mixture	1.1.1 Separation
			1.1.2 Separation & Concentration
	2. ANIMAL WASTE	2.1 Blood, Offal, Feathers, Bones	2.1.1 Incineration
			2.1.2 Oxidation
			2.1.3 Biological Treatment
			2.1.4 Solidification
	3. EXCRETA	3.1 Feces & Urine Combined	3.1.1 Incineration
			3.1.2 Oxidation
			3.1.3 Biological Treatment
			3.1.4 Solidification
	4. EDIBLE PRODUCT	4.1 Slaughtered Animal	4.1.1 Processing for Human Consumption
	5. INSENSIBLE WATER	5.1 Water Vapor	5.1.1 Condensation

FOLDOUT FRAME /.

CHART 3-O ANIMAL MODULE INPUT/OUTPUT M

ENABLING TECHNOLOGY	ADVANTAGES
1.1.1.1 Lithium Hydroxide	Simple
1.1.2.1 Active Centrifugal Separation	Low Pressure
1.1.2.2 Passive Centrifugal Separation	No Moving Parts - Simple - Low Cost - Separation Efficiency
1.1.2.3 Molecular Sieve	Reversible - Waste Heat Regeneration
1.1.2.4 Electrochemical Depolarized Concentrator	Continuous/Cyclic Removal - Generates DC Power - H_2O Removal
1.1.2.5 Solid Amine Resin	No H_2 or H_2O Removal Required
1.1.2.6 Membrane	Low Energy & Heat Rejection
2.1.1.1 Dry Incineration	Sterile Products - Ambient Pressure
2.1.2.1 Supercritical Water Oxidation	99% Efficient - Fast (1 min.) - Salt Separation in Aqueous Phase
2.1.2.2 Wet Oxidation	Sterile Products - High Water Quality - NH_3 for Plants Produced -
2.1.2.3 Electrochemical Oxidation	Low Temperature Requirements - High Value Chemical Feedstock
2.1.3.1 Aerobic Oxidation	
2.1.3.2 Anaerobic Digestion	High Solids in Feed - Methane & Carbon Dioxide Produced
2.1.3.3 Composting	Dry Material Treatment
2.1.4.1 Microwave Treatment	
3.1.1.1 Dry Incineration	Sterile Products - Ambient Pressure
3.1.2.1 Supercritical Water Oxidation	99% Efficient - Fast (1 min.) - Salt Separation in Aqueoue Phase
3.1.2.2 Wet Oxidation	Sterile Products - High Water Quality - NH_3 for Plants Produced -
3.1.2.3 Electrochemical Oxidation	Low Temperature Requirements - High Value Chemical Feedstocl
3.1.3.1 Aerobic Oxidation	
3.1.3.2 Anaerobic Digestion	High Solids in Feed - Methane & Carbon Dioxide Produced
3.1.3.3 Composting	Dry Material Treatment
3.1.4.1 Microwave Treatment	
4.1.1.1 Species Dependent	Provides Dietary Requirements - Psychological Benefits
5.1.1.1 Humidity Control Condensing Heat Exchangers	Simple - High Water Quality

FOLDC· ·AME 2

ETABOLIC ELEMENT ENABLING TECHNOLOGIES FOR A LUNAR BASE

	DISADVANTAGES
	Irreversible - Expendibles Required - Unacceptable for Long Missions
	Moving Mechanical Parts - Energy Required - Separation Efficiency
	High Pressure
	Recycle Energy Required - Periodic "Bake Out" Required
Not Required	Requires Oxygen Regeneration Subsystem
	High Heat Rejection - Requires Steam & Recycle
	Temperature (540 C) - VPCAR Required - Manual Load - N_2, Oxides of N Produced
	Temperature (377 C), Pressure (3000 psi), Power, Heat Rejection, Weight & Volume
Automatic	Temperature (300 C), Pressure (2000 psi) - Requires VPCAR Subsystem
Produced	N_2 Produced
	Energy Required - Low Solids - Toxic Upset Possible - Volume - Lead Time Required
	Toxic Upset Possible - Volume - Lead Time Required - Time of Cycle
	Volume
	Requires Disposal of Solidified Waste
	Temperature (540 C) - VPCAR Required - Manual Load - N_2, Oxides of N Produced
	Temperature (377 C), Pressure (3000 psi), Power, Heat Rejection, Weight & Volume
Automatic	Temperature (300 C), Pressure (2000 psi) - Requires VPCAR Subsystem
Produced	N_2 Produced
	Energy Required - Low Solids - Toxic Upset Possible - Volume - Lead Time Required
	Toxic Upset Possible - Volume - Lead Time Required - Time of Cycle
	Volume
	Requires Disposal of Solidified Waste
	Requires Processing - Adds Complexity
	May Require Post-treatment for Chemical & Biological Impurities

FOLDOUT FRAME 3

RISK	STATUS
	Used in Short Space Missions - Removes Only Carbon Dioxide
	Prototype System Operational - Research Required
Explosion	Prototype System Operational - Research Required
	Used on Skylab - Tradeoff Analysis Required
	Highly Developed - Tradeoff Analysis Required
	Tested for Submarine Air Purification - Tradeoff Analysis Required
	Early Development Stage - Research Required
Fire	Four Man System Built & Tested - Waste Feed About 50% Solids - Research Required
Explosion	Early Development Stage - Dilute or Concentrated Slurry Feed - Research Required
Explosion	Four Man Prototype for Space Habitats Built and Tested - Tradeoff Analysis Required
	Limited Laboratory Testing - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	Waste is not Recycled - Research Required
Fire	Four Man System Built & Tested - Waste Feed about 50% Solids - Research Required
Explosion	Early Development Stage - Dilute or Concentrated Slurry Feed - Research Required
Explosion	Four Man Prototype for Space Habitats Built & Tested - Tradeoff Analysis Required
	Limited Laboratory Testing - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	Not Tested for Space Environment - Research Required
	Waste is not Recycled
	Required for Greater System Closure

CHART 3-O

COLLECTION TECHNIQUE	RANKING	REFERENCES
1.1.1.1(1) Separation, Stored on LiOH	2	1
1.1.2.1(1) Direct/Storage	5	2
1.1.2.2(1) Direct/Storage	7	2
1.1.2.3(1) Carbon Dioxide Subsystems - Plant Module	7	1;3
1.1.2.4(1) Carbon Dioxide Subsystems - Plant Module	7	1;3
1.1.2.5(1) Carbon Dioxide Subsystems - Plant Module	6	1;3
1.1.2.6(1) Carbon Dioxide Subsystems - Plant Module	3	3
2.1.1.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	7	1;3;7
2.1.2.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	1;3;6;7
2.1.2.2(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	8	1;3;7
2.1.2.3(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
	1	9
	1	9
2.1.4.1(1) Disposal	2	2
3.1.1.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	7	1;3;7
3.1.2.1(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	1;3;6;7
3.1.2.2(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	8	1;3;7
3.1.2.3(1) CO_2 Subsystem or PM-Ash to PM-H_2O Storage	6	3;8
	1	9
	1	9
	1	9
3.1.4.1(1) Storage	2	2
4.1.1.1(1) Direct/Storage	5	11
	7	1